PHASING TRANSFORMER

O. L. RICHARDS
S. W. MC CUNE, JR.

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Design, construction, and
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DESIGN, CONSTRUCTION, AND TEST
OF A

PHASING TRANSFORMER

A THESIS

PRESENTED BY

OLIN L. RICHARDS SAMUEL W. McCUNE Jr.

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

G. M. Raymond

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CONTENTS

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History and development of the transformer........1

Three phase to two phase transformation...........6

The Scott Transformer..........................12

Design...22

Construction...................................36

Tests..45

Discussion.....................................56

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In discussing the history of a mechanical or electrical appliance our subject is naturally divided into three main parts, namely, its discovery or invention, its develelopement, and its modern applications. Although the transformer as it is today comes under the general head of electrical appliances, the division of its history into three main parts is not so marked, owing to the fact that, like many other electrical inventions, no sharp line of demarkation can be drawn between its discovery and develelopement.

As a starting point in the history of the transformer we may take the discovery of the principles of magnetic induction by Faraday. While experimenting in his laboratory he accidentally slipped one coil of wire over another and discovered that each time the circuit was closed through one of the coils a current of short duration flowed in the other. Investigating still further, he constructed an iron core in the shape of a ring

on which was wound two separate coils of wire. Upon closing the circuit of one of the coils through a battery he found that an electro-motive force was produced in the other of sufficient magnitude to produce sparks from its terminals. The results of his investigation were presented to the philosophical world in a paper read before the Philosophical Society of London on November 24th, 1831, and were published in the Transactions of the Society in November of the following year.

The next step in the developement occurred in the United States and was a crude form of our modern induction coil. This apparatus was an invention of Professor Henry's, and was first described in an article entitled "Methods and trials of obtaining physiological phenomena and sparks from a heat engine by means of Professor Henry's apparatus."

So remarkable was the invention of Professor Henry and a similar one in Europe by Ruhmkorff, that up to the year 1880 all efforts in the developement of the transformer were made with a view

of finding some practical application of the induction coil. Various arrangements were patented for employing the secondaries of several coils in series for lighting arc lamps, but all were without success.

Up to this point in our history one may say that the principles of the transformer as it is today were wholly unknown to the scientific world. The chief use of the modern transformer is for the distribution of power while the main idea in the use of the transformer of the period previous to 1880 was the division of power. By division of power we mean that a fixed amount of produced energy is divided into predetermined parts of certain number and size, while it remains indifferent, as far as the total energy is concerned, in what manner and how many of these parts are usefully employed.

In contrast with division of power we may define distribution as meaning that the energy produced is variable according to the variable requirements of consumption, the maximum requirement being predetermined from the number and size of the local

requirements, which also vary relatively to one another. From the above definition it is self evident that division of power implies the series method, while distribution of power implies the parallel.

With the invention of the incandescent lamp we see the first step in the developement of the transformer of the present day. In employing this system of lighting Edison demonstrated that the series method of connection was not suitable for any form of the glow lamp. He also showed by means of a system which he devised himself, that the parallel connection had several advantages in its favor. These facts, coupled with another and more important one, namely, the growing commercial use of electricity, thereby making it obligatory, in order to carry current economically to greater distances, to seek a new method of distribution, brought about the discovery of the principles of the transformer as we know them today.

The five years from 1880 to 1885 are filled with unsuccessful attempts to solve the problem of finding a self regulating and economical system of

current distribution with transformers which would fill the following conditions:

1. The generator must give a great difference of potential as constant as possible at the terminals of the transformers of the transformers, and also independent of the number fed.

2. The transformers must convert the current of high electro-motive force into a current of such electro-motive force as may be desired. The transformer must have a closed magnetic circuit, in order that all primary and secondary turns shall possess, relatively to the magnetic field, a like position, also in order that the resistances of the primary and secondary coils shall be so small that they cause practically no loss of electro-motive force.

The first system of current distribution which successfully met the above conditions was devised by Zipernowsky, Deri, and Blathy. The patents for their system were taken out on February 1[illegible]th, 188[illegible], entitled "Improvement in the means for regulation

of alternating electric currents." In the Inventions Exhibition of Budapest, Antwerp, and London their system was installed and received universal recognition, especially at the Budapest Exhibition. Here the several exhibits within a radius of 1400 meters were lit from a common central station. It was the first time that several electric circuits were so entirely independent of one another that lamps could be turned on and off without producing a change in the voltage of the other lamps.

As soon as this system had been successfully demonstrated in Europe it was immeadiately adopted in the United States, where as yet little interast had been shown in this branch of the electrical industry. From this time on, however, this country has taken the lead in developing our modern transformer. Of late years great strides have been made in the production of the high voltage transformer. Up to the year 1904, twenty thousand volts was considered about the highest working potential, while

thirty thousand volts was considered a possibility. During the last six years the progress in this direction has continued with ever greater rapidity until in the present year, 1910, commercial transformers of one hundred and ten thousand volts have been successfully installed

Three Phase

to

Two Phase

Transformation.

In the distribution of electrical energy from a central station there are two important factors which must be considered, namely, the power must be transmitted as economically as possible and delivered to the consumer in such a form as to adapt itself to the type of apparatus which is the most efficient from his point of view.

When power is transmitted over ling distances a high voltage is necessary in order that the cost of conduction shall not be excessively high for an allowable line loss. Although high voltage direct current systems have been employed successfully in some localities, it has not as yet been adopted in this country, the alternating current system being used wherever voltages of any magnitude are required.

In alternating current transmission several systems may be employed which are classified according to the number of wires used and the number of phases, as single phase, two phase, three phase, etc. Mr. C. P. Steinmetz has deduced the theoretical results shown in the table below, which gives the relative

weights, and therefore the costs, of line wire; the amount of power transmitted, the line loss, the distances transmitted and the maximum voltage between wires being constant.

Single phase, two wire,	100.
Quarter phase, three wire,	145.7
Quarter phase, four wire,	100.
Three phase, three wire,	75.

From the above table it will be seen that from the point of view of economy the three phase system of distribution is the one to be chosen.

From the point of view of the consumer three phase distribution may not be as convenient, and in some cases may even be less efficient than two phase distribution. The matter of efficiency applies more to the first cost of apparatus than to actual running efficiency. Also with regard to power measurements and switch board design, two phase distribution is sometimes found to be more convenient where skilled labor is difficult to obtain and where first cost is an important consideration.

It is evident from the above discussion that a device for changing three phase power to two phase is required in order that the distribution may be the most efficient from both the company's and consumers point of view. The Scott method of connection is one of the many for transforming three phase power into two phase and vice versa.

The Scott Transformer.

In a paper read by Mr. Charles F. Scott, in 1894 before the National Electric Light Association, there was described a method of transforming currents of one phase into currents of different phase as follows;" If two E.M.F's differing in phase by 90 degrees be connected in series, the resultant E.M.F. is represented in direction and magnitude by the hypothenuse of a right-angled triangle, of which two of the sides are the two component E.M.F's. Then in Fig. 1, if OA and OB are two E.M.F's at right-angles, and these E.M.F's be connected in series the resulaant is the line AB, of a different phase from either of the components. It is a simple matter to so proportion the components so that OB is equal to one half ofAB, as shown in the diagram. In a similar manner it is readily seen that the same E.M.F. OA may be combined with OC, which differs from it by 90 degrees(but is equal and opposite to OB) in such a way as to give AC equal to AB, but differing in direction: BO and OC added together give BC. The E.M.F. BC may therefore be combined with the E.M.F. AO, at right angles to it, in such a way as to give

additional E.M.F's, which in connection with BC give three equal E.M.F's 120 degrees apart. This is the relation of E.M.F's in the three phase system.

The application of this arrangement to transformers is illustrated in the accompanying Figures 2 and 3. The primaries of two transformers are connected to a generator giving two phase current. The secondary E.M.F's therefore differ by 90 degrees. One secondary is made equal to100 turns and a loop is brought out giving 50 turns at each side. The second secondary has 87 turns, which is approximately equal to 50 multiplied by the square root of three. One end of this secondary is connected to the middle point of the secondary of the first transformer as shown, and these three free terminals will then deliver E.M.F's differing in phase by 120 degrees. If the E.M.F. in each primary be 1000 volts and on one secondary 100 volts, and on the other secondary 87 volts, then the E.M.F. measured between any two secondary terminals will be 100 volts as shown.

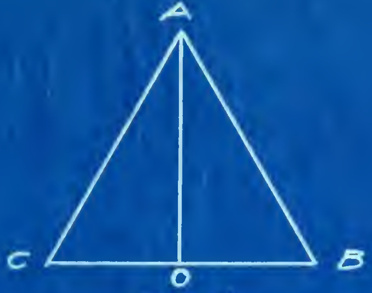


Fig. 1

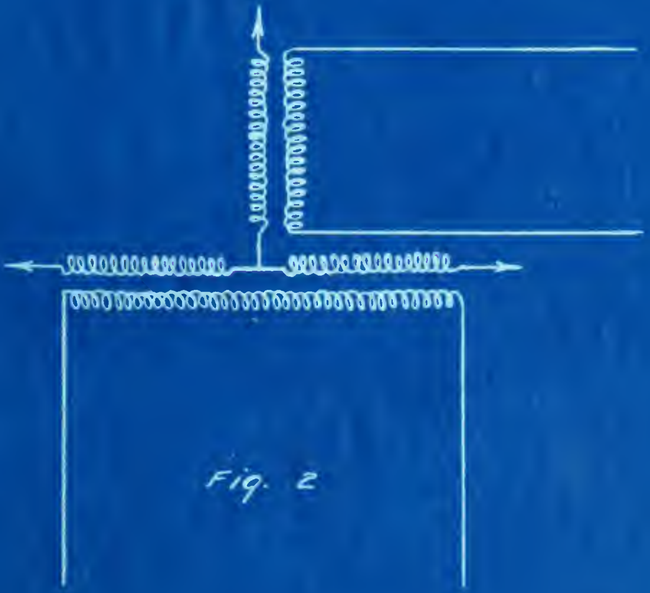


Fig. 2

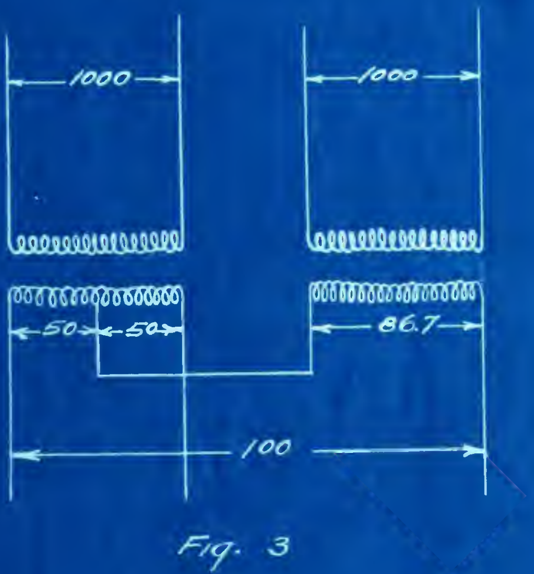


Fig. 3

The voltage relations in the Scott type of a phasing transformer may be conveniently explained by the vectorial method.

In figure 4 let a, b, and c be the vectors representing three phase e.m.f. By reversing the e.m.f. b we obtain the e.m.f. relation a, b', c shown in figure 5. If now we increase the voltage a by varying the number of turns on the primary, until it equals the voltage d, which is obtained by combining the two e.m.f.'s b' and c in series, it is evident that two phase voltage relations are obtained.

By revolving the vectors a, b, and c about o we may obtain the sine wave voltage relations shown in figures 7, 8, and 9. In figure 7 the curves a, b, and c are plotted between the three phase voltage values and electrical degrees. By reversing the voltage c we obtain the voltage relation shown in figure 8, where c' is the reversed voltage. As in the vectorial representation the amplitude is increased to a' by varying the number of turns on the secondary.

Voltages b and c' are then placed in series and the two phase voltage relations are obtained as previously shown.

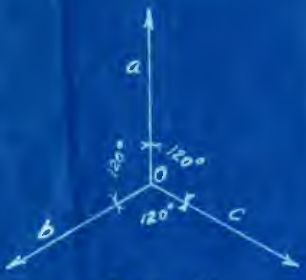


Fig. 4

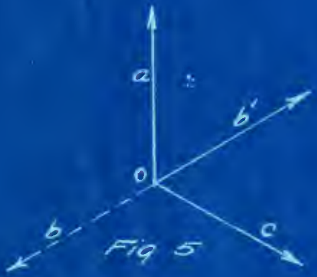


Fig 5

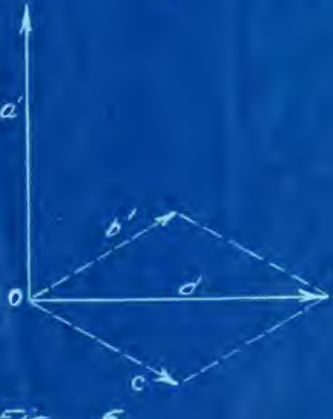
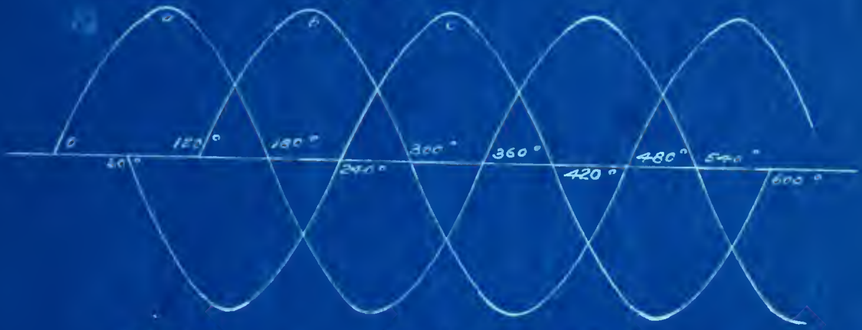


Fig 6

Fig. 7


a
b
c
0
60°
120°
180°
240°
300°
360°
420°
480°
540°
600°

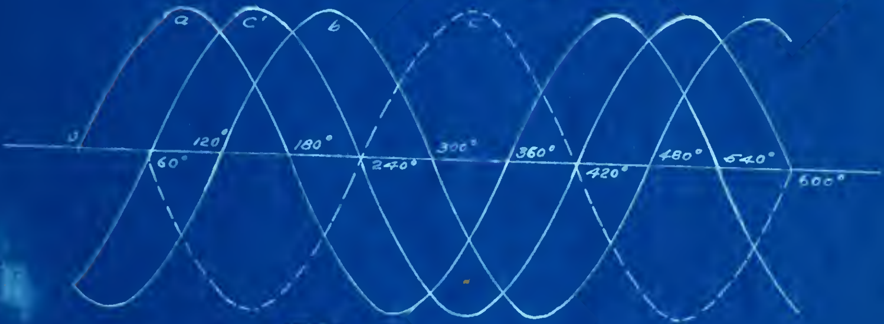

a
C'
b
C
0
60°
120°
180°
240°
300°
360°
420°
480°
540°
600°

Fig. 8

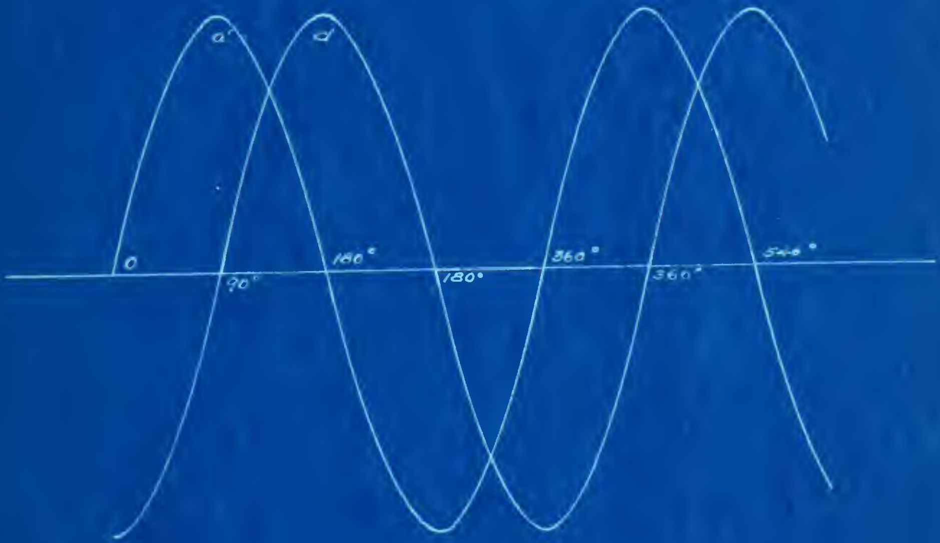


Fig. 9.

Design.

The object of this thesis is the design and construction of a phasing transformer of the Scott type, the theory of which has been given in the preceding section. No set methods of design will be used, the method which seems to meet each particular case being applied in each instance.

The following are the constants which have been assumed:-

1. Output in K.W.	10
2. Cycles per second.	60
3. Primary voltage.	110
4. Ratio of transformation.	1
5. Flux density in lines per sq. in.	30000
6. Type	Shell
7. Current density in circ. mills per ampere .	1500
8. Steinmetz' Coefficient	.0021
9. Thickness of core laminations in inches . .	.012
10. Eddy Current loss constant, ...	1.6×10^{-11}
11. Permeability of the iron	2600

The transformer core, the assembly of which is shown in figures 11 and 12, and the details in figure 10, is to be constructed with stampings of good quality iron and will be obtained by dismanteling an old transformer of the same output as the proposed.

A phasing transformer of the Scott type is virtually two transformers with their secondaries interconnected. However, since there is a phase difference of 90 degrees in the fluxes of these transformers a saving of iron is secured by constructing the two cores together, the common core, which would have an aggregated width of three inches if constructed separately, having a width of $\sqrt{\frac{1}{2}}$ times three inches or two and one quarter inches.

This method of core construction does not introduce any complications in the design of the remainder of the transformer and therefore we will consider only one half of the transformer in our computations.

The general equation for the E.M.F. of a transformer is

$$E = \sqrt{2}\pi fNAB_m \times 10^{-8}$$

Where E is the induced voltage (effective value)

f = frequency in cycles per second

N = number of turns

A = cross sectional area of core in any chosen units.

B = maximum instantaneous value of the flux density in lines per unit area.

Solving the above equation for N we obtain

$$N = \frac{10^8 E}{\sqrt{2}\pi f A B_m} \qquad (2)$$

From the dimensions of the core in figure 11 we find

A is 7.5 x 3 = 22.5 square inches

Substituting this value and the assumed ones of E, f, and B in equation 1 we have

$$N = \frac{10^8 \times 110}{\sqrt{2} \cdot 3.1416 \times 60 \times 22.5 \times 60000}$$

$$= 44 \text{ turns.}$$

The three phase side of the transformer is consider edto be the primary and the two phase side the secondary inasmuch as these are the conditions usually met with in practice. Since the ratio of transformation has been

assumed as one, the above will be the number of turns on each secondary and between one phase of the primary. The number of turns on the "T" connection of the primary will be-

$$.866 \times 44 = 38 \text{ turns}$$

The volume of the iron in the core, calculated from the constants of the stampings, is 885 cubic inches.

The weight corresponding to this volume is 248 lbs.

The weight of iron per K.W. is 14.8 lbs.

Dr. C. P. Steinmetz has deduced a formula for the watts lost due to hysterysis effects in the iron which is

$$P = VfnB^{1.6} \times 10^{-7} \qquad (3)$$

where V is the volume of the iron in the core in cubic centimeters.
f is the frequency in cycles per second.

n is the coefficient depending on the quality of the iron used.

B is the flux density in Gauses (maximum instantaneous)

Substituting the calculated values and the assumed ones of V, f, and B in formula (3) we obtain

$$P = \frac{885 \times 60 \times 4650 \times 1.6 \times .0021}{.061 \times 10^{7}} = 1.36 \text{ watts.}$$

An empirical formula used in transformer design for the calculation of the watts loss in the transformer core due to eddy currents, based upon the assumption that the laminations are perfectly insulated from one another is

$$P_e = K v f^2 l^2 B_m^2 \times 10^{-11} \qquad (4)$$

where

K is a constant depending upon the resistivity of the iron.

v is the volume of the iron in cubic centimeters.

l is the thickness of one lamina in centimeters.

f is the frequency in cycles per second

B is the maximum flux density in gauses.

Substituting the calculated values and the assumed ones of 2, 5, 9, and 10 in equation (4) we have

$$P = \frac{1.6 \times 10^{-11} \times 655 \times 3600 \times .000144 \times}{.061} \text{[illegible]}.17 \times 10$$

$$= 25.2 \text{ watts}$$

The total iron loss will therefore be

25.2 + 130 = 155.2 watts

The iron loss current per wire on the three phase side of the transformer is

$$\frac{155.2}{\sqrt{3} \times 110} = \quad 2.96 \text{ amperes}$$

Representing the reluctance of the core by R, and the magneto-motive force necessary to produce the flux ϕ_m by H we have

$$\phi = \frac{H}{R} = \frac{\frac{4\pi nI}{10}}{R} \qquad (5)$$

whence

$$I = \frac{10\,R\,\phi}{4\pi n} = \frac{10\,R\,\phi_m}{4\sqrt{2}\,\pi n} \qquad (6)$$

where

$$R = \frac{l}{\mu A} \qquad (7)$$

we have

$$I = \frac{10\,l\,\phi_m}{4\sqrt{2}\,\pi n\mu A} = \frac{10\,l\,B_m}{4\sqrt{2}\,\pi n\mu} \qquad (8)$$

where l is the length of the magnetic circuit in centimeters.

B_m is the maximum value of the flux in gausses.

μ is the permeability of the iron.

N is the number of turns.

I is the magnetizing current in amperes.

The length of the magnetic path calculated from the dimensions of the core is 21.5 inches.

Substituting the calculated values and the observed

ones of 5 and 11, we have

$$I_{mag} = \frac{10 \times 4650 \times 21.5 \times 2.54}{4 \times \sqrt{2} \times 3.1416 \times 44 \times 2600}$$

1.25 amperes per phase on the two phase side.

I_{mag} per wire on the three phase side is

$$\frac{1.25}{.866} = 1.443 \text{ amperes}$$

The no load current per wire is

$$I_{exc} = \sqrt{\overline{2.96}^2 + \overline{1.443}^2} = 3.295$$

The no load power factor is

$$\phi = \frac{155.2}{\sqrt{3} \times 110 \times 3.295} = .245$$

The total length of the winding of one primary was calculated, knowing the mean length of one turn and the number of turns, as follows:

Total number of turns on one phase of the secondary is 44. Assume this number of turns to be distributed equally among four coils of eleven turns each. The mean length of one turn of one of these coils, allowing two inches for each corner, is two and one-half

feet and the total length of one secondary is

$$2.5 \times 11 \times 4 = 110 \text{ feet}$$

The current per phase on the two phase side at full load is

$$I = \frac{5000}{110} = 45.5 \text{ amperes.}$$

and the current on the three phase side is

$$I = \frac{10000}{\sqrt{3} \times 110} = 52.5 \text{ amperes.}$$

A current density of 1200 circular mils per ampere assumed. This value gives a required circular mil area on the three phase side of 6300[illegible] and on the two phase side 54500. Four wires, B. and S. gauge 8, in parallel gives a combined circular mil area of 66000 which gives a sufficiently low current density.

From the wire tables this gauge is found to have a resistance per foot as follows:

At 20° C.	At 50° C	At 80° C
.0006271	.0007007	.00077[illegible]

The resistance per foot when four are in parallel is:

At 20° C	At 50° C	At 80° C
.0001568	.0001752	.0001911

and the resistance for each secondary and one of the primary windings is.

At 20° C	At 50° C	At 80° C
.017248	.019272	.021351

The resistance of the primary which has thirty-eight turns is:

At 20° C	At 50° C	At 80° C
.01488	.01663	.01841

The resistance measured between the other two wires of the primary will be

At 20° C	At 50° C	At 80° C
.023504	.026266	.029085

Also from the wire tables we find that the number of pounds per foot for #8 wire is .04998 and hence the total weight of one secondary is

4 x 110 .04998 = 22 pounds

The weight of the three sets of coils containing 44 turns each is 66 pounds. Since the connection of the primary will have only .87 as many turns as its secondary, the weight of this set of coils is

.87 x 22 = 19.14 pounds

and the total weight of the copper used is 85.14 pounds.

Weight of copper per K.W.

$$\frac{85.14}{10} = 8.5$$

RI drop at full load

$$.0359 \times 52.5 = 1.88$$

$$.01928 \times 45.5 = \underline{.828}$$

$$2.708$$

I^2R loss at full load

$$52.5 \times 1.88 = 97.5 \qquad 97.5$$

$$45.5 \times .828 = 37.7 \times 2 \qquad \underline{75.4}$$

$$172.9$$

Total loss

$$155.2$$

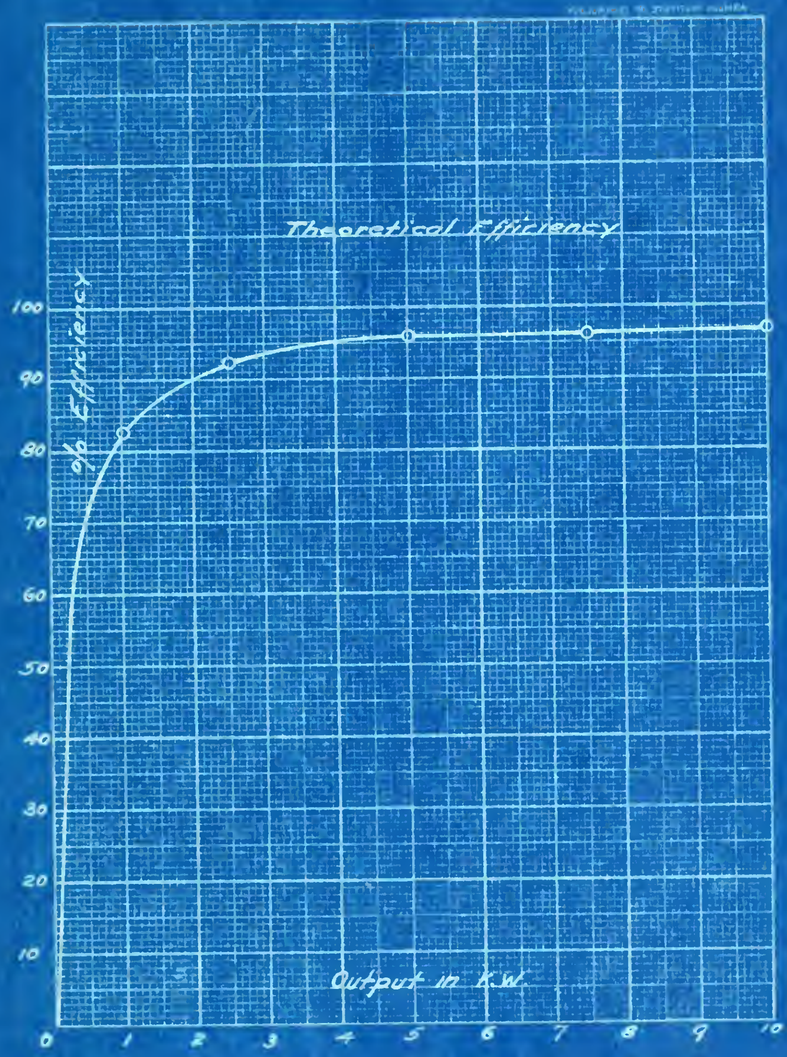
$$\underline{172.9}$$

$$328.1$$

Recapitulation.

1. Output in K.W.	10.
2. Cycles per second	60.
3. Primary voltage	110.
4. Sedondary voltage	110.
5. Primary current per wire in amperes	52.5
6. Secondary current per wire in amperes	45.5
7. Flux density in lines per square inch.	30000.
8. Type	Shell
9. Number of primary turns per phase	44 and 38
10. Number of secondary turns per phase	44.
11. Volume of iron in cubic inches	355.
12. Weight of iron in lbs.	248.
13. Weight of iron per K.W.	24.8.
14. Weight of copper in pounds	85.
15. Weight of copper per K.W. in lbs.	8.5
16. Weight of insulated copper in lbs.	95.
17. Total weight in lbs.	343.
18. Pounds per K.W.	34.3

19.	Hysterysis loss in watts	130.
20.	Eddy Current loss in watts	25.2
21.	Total iron loss in watts	155.2
22.	Iron loss current in amperes, three phase side per wire	2.96
23.	Magnetizing current, three phase side per wire ..	1.44
24	No load current in amperes, three phase side per wire ..	3.30
25.	No load power factor	.248
26.	Mean lenght of one turn, in feet	2.5
27.	Resistance of each secondary in ohms..	.0195
28.	Resistance of primary, equivalent ...	.0[illegible]59
29.	RI drop per phase at full load in volts	2.708
30.	Total I R loss at full load in watts...	172.9
31.	Total loss at full load in watts	328.1
32	Efficiency at full load in %	96.2
33.	Efficiency at 3/4 load in %	96.2
34.	Efficiency at 1/2 load in %	95.9
35.	Efficiency at 1/4 load in %	92.4


Theoretical Efficiency
% Efficiency
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
Output in K.W.

Construction.

In building a transformer the principle points to be considered are the construction of the coils, the assembling of the core, and the arrangement of the two in a compact frame to provide stability.

The coils of this transformer were made from No. 8 B. & S. gauge double cotton covered copper wire. Four strands of this wire were bound together with tape into a flat ribbon in order to give a conductor of the required circular mil area.

For winding the coils a wooden form was employed having a core 9 x 3 x 1/2 inches, the periphery of which exactly gave the circumference of the core of the transformer. Two heavy boards of 1 1/2 inch timber and a foot and a quarter long, were bolted on either side of the wooden core so as to hold the wire compact during construction and prevent spreading. The number of turns on a completed coil varied; there being six coils of eleven turns each, nine coils of nine turns each, and one coil of 7. 4 turns , thus making 16 coils all together. In building the coils one more turn than required was wound , the first turn being afterwards

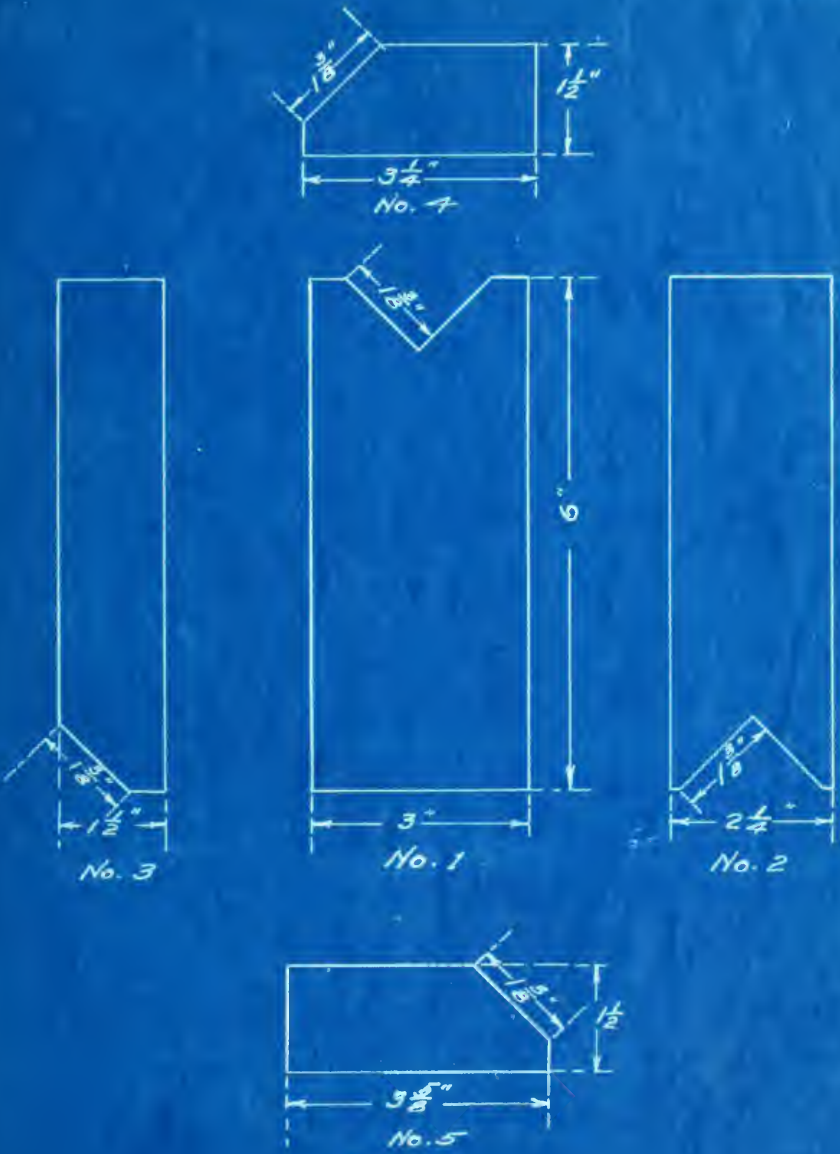
removed to allow for insukation between the core of the transformer and the coil. Having completed the coils they were each tested separately for shorts and found to be in good shape. The arrangement of the coils in their proper position was next made, a secondary being interspersed between each primary as shown in figure 15. It remained now to connect the primaries and secondaries of each transformer together. To accomplish this the insulation was scraped from each wire for a length of three inches and the strands twisted tightly together, after which the joint was soldered and covered with a rubber insulating tape. The coils being completed the core was next built about them.

The frame, shown in figures 13 and 14, was obtained from the dismanteled transformer and the coils were placed in it. In figure 10 are shown the stampings for the core. They are cut into five different sizes, there being four pieces of No. 1 ; two of No. 2; four of No. 3; four of No. 4, and 12 of No. 5 in each layer of the core

These stampings were all put in by hand, and each side of the core built up simultaneously layer upon layer. In order to get the required height of stampings the core had to be frequently c ompressed, and clamped down while the laminations were inserted. In this manner 71/2 inches of the core was completed.

A preliminary test was next made and it was found that the transformer worked as designed giving three phase voltage when two phase voltage was applied and vice versa. There remained only to place the transformer as built in the metal oil tank, and the transforme r was completed and ready for complete tests.

STAMPINGS FOR CORE



No. 4

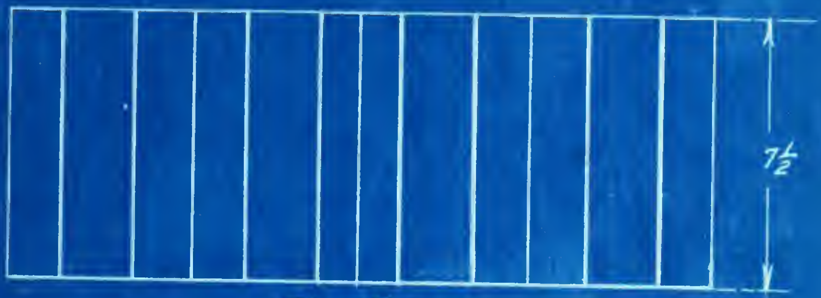
No. 3

No. 1

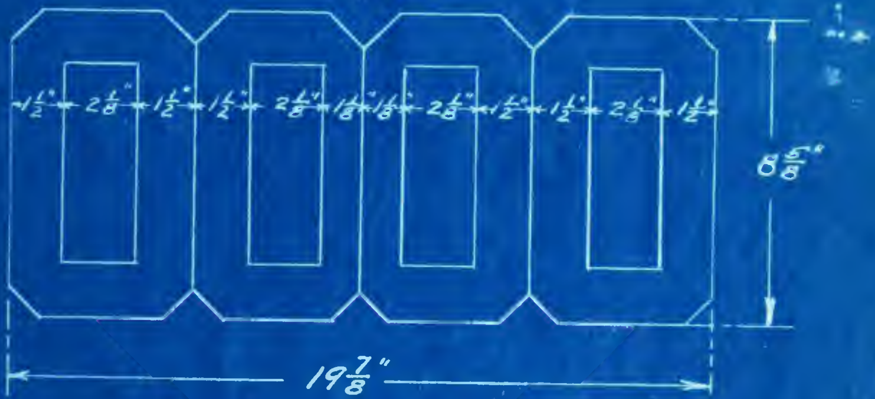
No. 2

No. 5

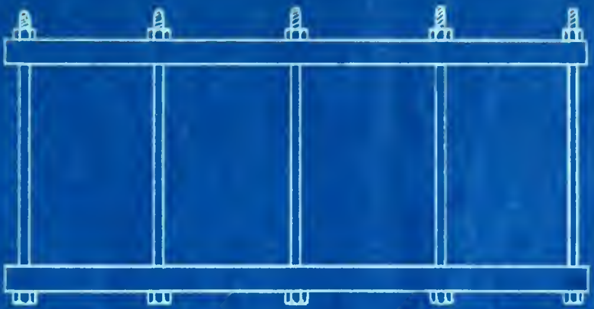
Fig. 10



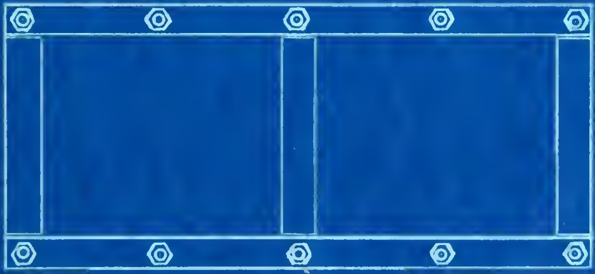
Elevation
Fig. 11



Plan
Fig. 12



ELEVATION
Fig. 13



PLAN
Fig. 14

FRAME OF TRANSFORMER

ARRANGEMENT OF COILS

PRIMARY	11 TURNS
SECONDARY	11 " "
PRIMARY	11 " "
SECONDARY	11 " "
PRIMARY	11 " "
SECONDARY	11 " "
PRIMARY	11 " "
SECONDARY	11 " "

PRIMARY	11 TURNS
SECONDARY	9 " "
PRIMARY	11 " "
SECONDARY	9 " "
PRIMARY	11 " "
SECONDARY	10 " "
PRIMARY	11 " "
SECONDARY	9 " "

Fig. 15

FORM FOR WINDING COILS

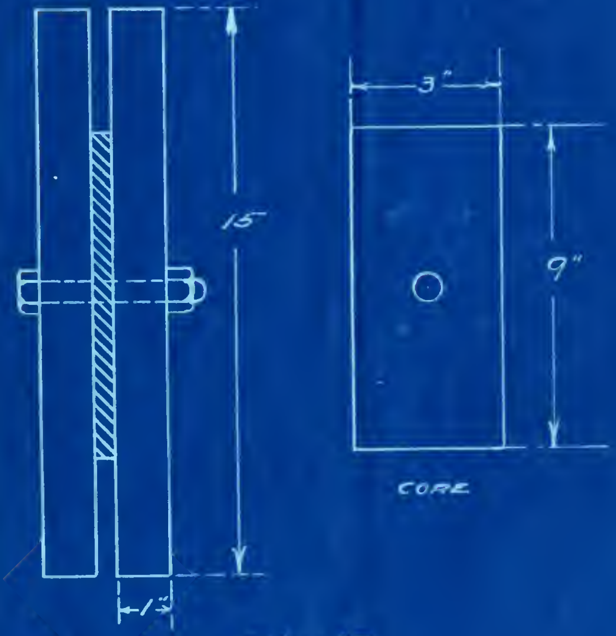


Fig. 16

Tests.

EFFICIENCY TEST.

1.	2.		3.		4.
Test	Phase #1		Phase #2		Phase #3
Number	Watts	Amperes	Watts	Amperes	Amperes
1	5800	57.5	5000	57.	56.
2	5250	51.3	4400	50.	49.3
3	4660	45.9	4030	46.5	43.4
4	4050	39.5	3450	39.2	[illegible]
5	3530	34.3	3050	35.	[illegible]
6	3000	29	2520	23.[illegible]	27.3
7	2400	22.8	2000	23.3	[illegible]
8	2020	19.	1550	16.[illegible]	17.[illegible]
9	14[illegible]0	13.4	1080	13.5	12.
10	375	3.84	-35	4.62	3.78

EFFICIENCY TEST. (continued)

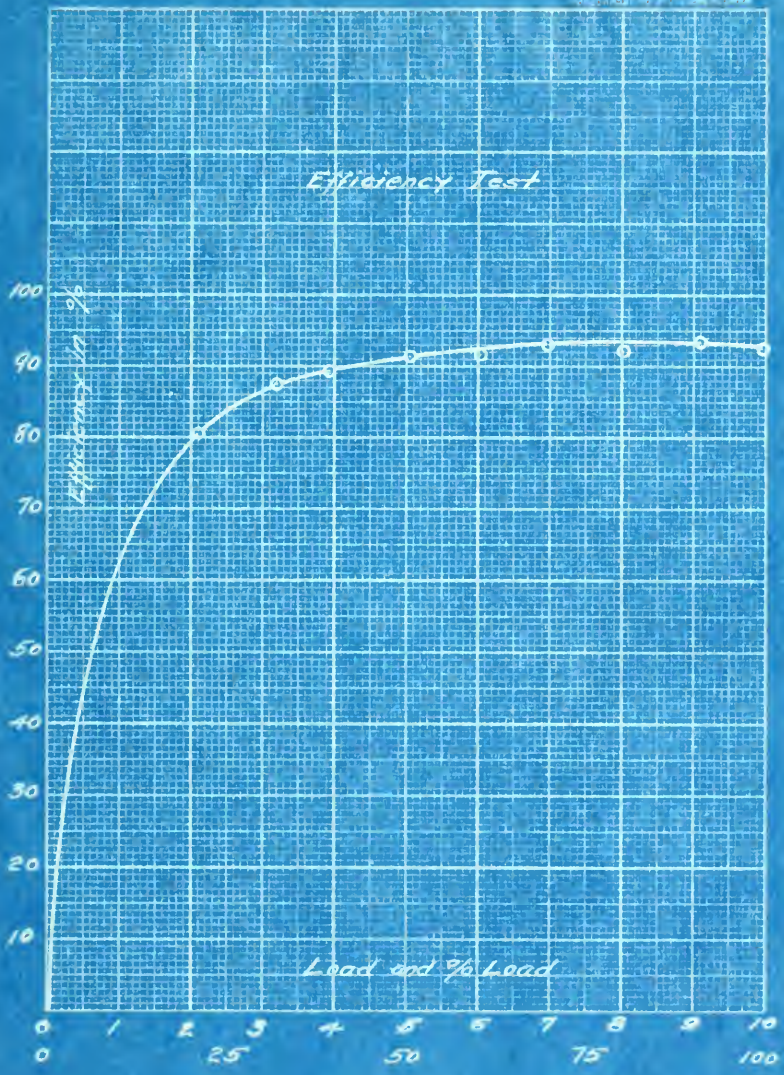
5.	6.	7.	8.
Average Values.			
Current per wire	Line Voltage	Frequency in cycles	Apparent Power
56.66	110	60	10783
50.27	110	60	9575
45.26	110	60	8650
38.66	110	60	7360
33.96	110	60	6470
28.66	110	60	5465
22.6	110	60	4310
18.53	110	60	3516
12.96	110	60	2478
4.08	110	60	777.24

EFFICIENCY TEST. (Continued

9.	10.	11.	12.
		Two Phase Output.	
True Power.	Power Factor.	Phase #1 Watts.	Phase #2 Watts.
10800	1	4960	5000
9680	1	4420	4600
8690	1	4025	3950
7500	1	3440	3490
6580	1	3040	2970
5520	1	2550	2470
4400	1	1970	1940
3570	1	1550	1580
2560	1	1010	1040
340	.438	No Load.	No Load.

EFFICIENCY TEST. (Continued.)

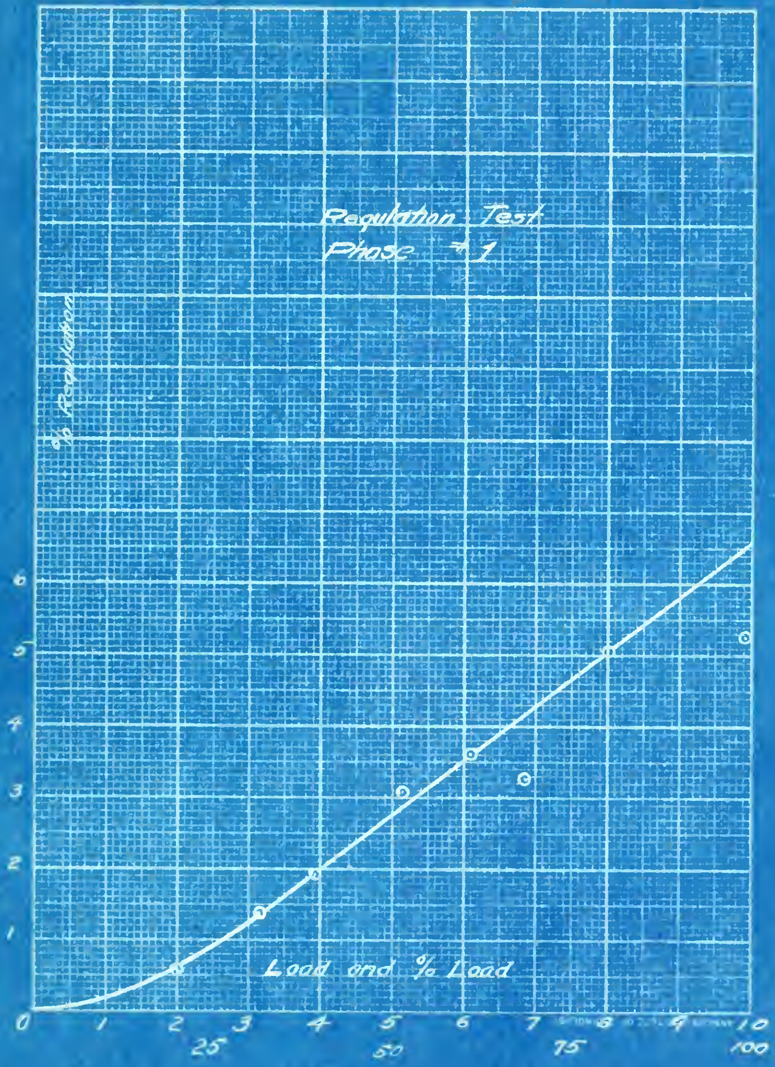
13.	14.	15.	16.
Power Output	Observed % Efficiency	Calculated % Efficiency	Per Cent Load
9960	92.3	93.2	99.6
9020	93.1	93.	90.2
7975	91.9	93.	79.75
6930	92.5	92.9	69.3
6010	91.5	92.8	60.1
5020	91.1	92.4	50.2
3910	89.	91.8	39.1
3130	87.7	89.5	31.3
2050	80.2	86.	20.5
No Load	0.	0.	0.


Efficiency Test
Efficiency in %
100
90
80
70
60
50
40
30
20
10
Load and % Load
0
1
2
3
4
5
6
7
8
9
10
0
25
50
75
100

Regulation Test.

Phase #1

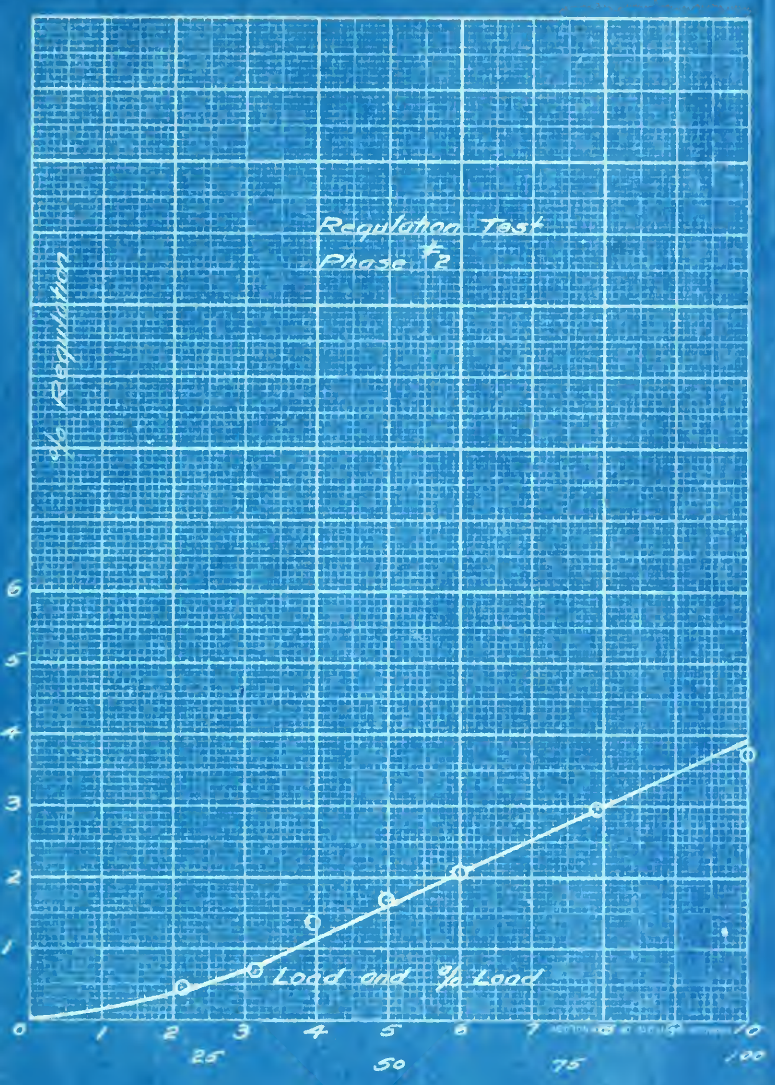
Watts	Amperes	Volts	% Regulation.
4960	47.5	105	5.24
4420	41.5	106.8	5.47
4025	38.2	105.2	5.04
3440	32.2	107.	3.27
3040	28.4	106.6	3.66
2550	23.7	107.2	3.08
1970	18.2	108.5	1.85
1550	14.3	109.	1.375
1010	9.7	109.9	.545
0	0.	110.5	0.00


Regulation Test
Phase #1
% Regulation
Load and % Load
0
1
2
3
4
5
6
0
1
2
3
4
5
6
7
8
9
10
25
50
75
100

Regulation Test.

Phase 2

Watts	Amperes	Volts	% Regulation
5000	46.5	107.0	3.74
4600	42.2	107.8	2.97
3950	36.4	107.8	2.97
3490	31.4	109.2	1.648
2970	26.8	108.8	2.02
2470	21.7	109.2	1.648
1940	17.0	109.5	1.37
1580	13.8	110.3	.635
1040	8.0	110.5	.435
0	0	111.0	.00


Regulation Test
Phase #2
% Regulation
Load and % Load
0
1
2
3
4
5
6
7
10
25
50
75
100

Separation of Iron Losses.

Voltage	Frequency	Watts		Total
		Phase #1	Phase #2	Power.
110	60	375	-35	340
73.25	40	270	-50	220

Hysteresis loss in watts 310

Eddy current loss in watts 30

All day efficiency, 19 hours full load, 92.8%

CALCULATED TRANSFORMER LOSSES.

Secondary Copper Loss	Primary Copper Loss	Total Copper Loss	Total Loss
112.	296.9	408.9	748.9
87.	233.8	320.8	660.8
69.2	189.3	258.5	598.5
50.5	138.3	188.8	528.8
38.	106.4	144.4	484.4
25.75	76.1	101.85	441.85
15.41	48.1	63.51	403.51
9.81	31.6	41.41	381.41
4.24	15.53	19.77	359.77
0.	1.53	1.53	340.

Number of Instruments Used.

Alternating Current Instruments.

Wattmeters.

Weston Electric Company	0 to 15	#1791
Weston Electric Company	0 to 15	# 467
Weston Electric Company	0 to 7.5	#1778
Weston Electric Company	0 to 750	#3732

Ammeters.

General Electric Company	0 to 50	#24081
General Electric Company	0 to 50	#70511
General Electric Company	0 to 100	#48835
General Electric Company	0 to 5	#144085

Voltmeters.

Weston Electric Company	0 to 120	#5091
Weston Electric Company	0 to 150	#2674
Weston Electric Company	0 to 150	# 753

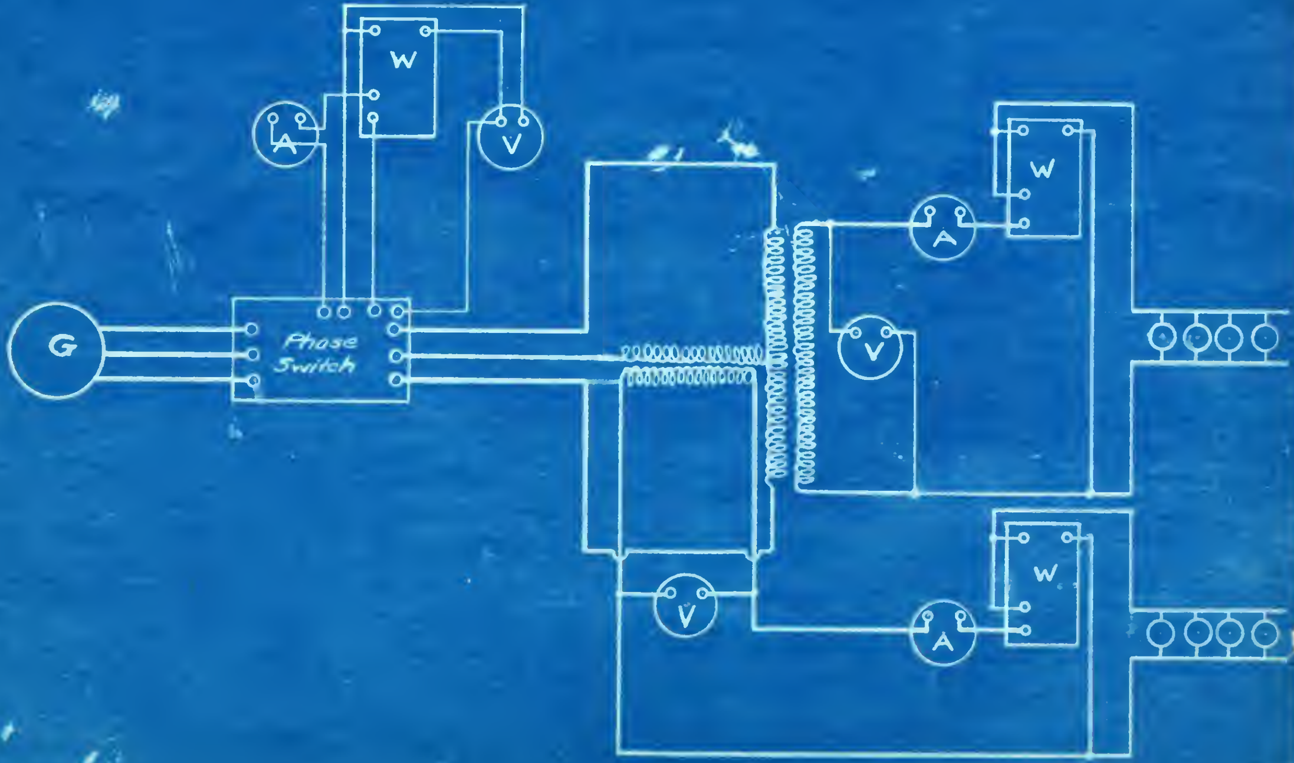
Direct Current Instruments.

Voltmeters.

Weston Electric Company	0 to 15	#14830
Weston Electric Company	0 to 15	# 4403

Ammeters.

Weston Electric Company	0 to 50	# 2098



Scheme of Connections

Discussion.

Comparison between Design and Actual Values.

	Calculated	Actual
1. Output in K.W.	10	10
2. Frequency	60	60
3. Primary voltage	110	110
4. Secondary voltage	110	110
5. Primary current per wire	52.5	52.5
6. Secondary current per wire	45.5	45.5
7. Flux density, lines per sq. in.	30000.	37300.
8. Type	Shell	Shell
9. Number of primary turns per phase	44 & 38	40 & 35
10. Number of secondary turns per phase	44.	40.
11. Volume of iron in cir. in.	855.	650.
12. Weight of iron in lbs.	248.	159.
13. Weight of iron per K.W.	24.8	15.9
14. Weight of copper in pounds	65.	86.
15. Weight of copper insulated	95.	96.
16. Weight of copper per K.W.	9.5	9.6
17. Total weight in pounds	343.	255.
18. Pounds per K.W.	34.3	25.5

	Calculated	Actual
19. Hysteresis loss in watts	130	310.
20. Eddy current loss in watts	25.2	30.
21. Total iron loss in watts	155.2	340.
22. Iron loss current in amperes, three phase side per wire	2.96	3.09
23. Magnetizing current per wire, three phase side per wire	1.443	2.[illegible]5
24. No load current in amperes, three phase side per wire	3.3	4.[illegible]
25. No load power factor	848	.438
26. Mean length of one turn in feet	2.5	[illegible]
27. Resistance of primary equivalent	.0[illegible]	.04[illegible]15
28. Resistance of each secondary in ohms	.0195	.0245
29. RI drop per phase at full load in volts	2.708	4.7
30. Total I^2R loss at full load in watts	172.9	340.
31. Total loss at full load in watts	328.1	680.
32. Efficiency at full load	96.72	9[illegible]
33. Efficiency at 3/4 load	96.2	93.[illegible]
34. Efficiency at 1/2 load	95.9	91.2
35. Efficiency at 1/4 load	94.4	[illegible]

In the preceding table a comparison is given between the calculated and actual values from which it can be easily seen how far theory follows practice.

It will be noticed that there is a difference between the two values of secondary current per wire. This is due to the fact that owing to the regulation of the transformer a greater value of current was required on the two phase side in order that the full load output might be obtained.

The actual value of flux density is greater than the calculated due to the lesser number of turns used. Owing to difficulties which arose in the construction it was found impossible to employ 44 turns. For like reason the volume of iron in the core is also smaller than the calculated.

There is a large difference in the two values of watts lost in hysteresis. This is due partly to the fact that a higher value of flux density was used, and partly to the fact that a poorer quality of iron was employed than was assumed in the calculation. Solving the Steinmatz equation for the coefficient for the iron used the value .0047 is obtained.

The difference in the two values of eddy current is due to different volume and induction density being used. Solving the eddy current loss equation for the resistivity constant the value 1.7 is obtained.

The variance in the values of the remaining items is due to facts already discussed and to different methods used in construction than were assumed in the design.

The chief source of error which the majority of results are liable to was the fact that a number of instruments were read by two persons and therefore it was extremely difficult to obtain simultaneous readings.

Considering the meager facilities at hand for the construction of the different parts of the transformer, the results on the whole are very satisfactory.